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ABSTRACT

In this study, the author attempts to identify feasible new appointment schedules for a large tenure and nontenure faculty group in which quota restrictions have been applied to the total number of faculty appointments. It is assumed that the system is in equilibrium in the sense that the flow rate of new appointments is equal to the sum of resignation, retirement, and death rates. Several models were formulated and discussed at the University of California in the fall of 1967; it soon became apparent that there was a need for a simple, informal explanation and discussion of the more complicated statistical models used to predict faculty movements, promotions, resignations, and changes in rank and age distributions with the passage of time for the planning purposes of institutional administrators. This report is intended to be such a device for explaining the underlying patterns of tenure and nontenure personnel movements, and as a model for estimating the magnitude of these flows and the qualitative effect of new appointments on promotions policies. (Author)

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AN EQUILIBRIUM MODEL OF FACULTY APPOINTMENTS, PROMOTIONS, AND QUOTA RESTRICTIONS

Robert M. Oliver

Research Report No. 69-10
March 1969

ABSTRACT

In this study, the author attempts to identify feasible new appointment schedules for a large tenure and nontenure faculty group in which quota restrictions have been applied to the total number of faculty appointments. It is assumed the system is in equilibrium in the sense that the flow rate of new appointments is equal to the sum of resignation, retirement , and death rates.

This research was initially funded by a grant from the National Science Foundation to the Chancellor's Office of the Berkeley Campus, University of California. The project was administered by the Office of Institutional Research on that campus and coordinated by the Director of Institutional Research, S. Suslow, to whose encouragement and stimulation the author is indebted.

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The original version of this report was intended to be such a device for explaining the underlying patterns of nontenure and tenure personnel movements, and as a model for estimating the magnitude of these flows and the qualitative effect of new appointment or promotion policies.

Although the report was written and distributed before the Ford Foundation Project in University Administration had been initiated, a number of requests for the report have recently been received. Since the topic appears to be in keeping with other studies of a similar type now being supported by the Ford Foundation, we are reprinting the original version with only minor editorial changes.

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I. INTRODUCTION

1. The Problems

The purpose of this report is to discuss some of the long-run planning and staffing problems associated with academic positions on the Berkeley campus of the University of California. It has been recognized for some time that the academic staff is heavily weighted in the tenure ranks and that, with the passage of time, the relative fraction and age of tenure faculty will increase. A faculty whose distribution is heavily weighted in the tenure ranks has both advantages and disadvantages that we can discuss in qualitative ways. The experience and wisdom of age and familiarity with the problems of teaching, conducting research, and advising students is a definite asset. However, from the economic viewpoint, and certainly from the point of view of those concerned with the long-run morale and stability of a large faculty body, large numbers of tenure faculty will give rise to increasing academic salary costs and fewer opportunities for many in the advanced ranks to continue receiving the salary raises and promotions that they warrant. If tenure faculty ranks are large in proportion to nontenure, the opportunities to appoint new nontenure faculty will become severely limited and there may be a reduction of the infusion of new people, new ideas, and youthfulness that has been so characteristic of our campuses.

The tendency towards a long-run or equilibrium pattern with large numbers of tenure faculty is accelerated by several factors: (1) new appointments to tenure ranks, (2) new appointments at high levels of nontenure ranks which feed tenure ranks, (3) a retirement system that encourages long service lifetimes, (4) a high probability that a nontenure appointment will eventually make tenure, (5) the relatively short lifetimes in nontenure ranks, and (6) accelerated promotions.

Most of these effects can be traced to the competitive nature of markets for young faculty of high creative potential. The short nontenure lifetimes, the large number of appointments to tenure and accelerated promotion rates is largely due to our attempt to use the higher ranks to achieve higher salaried positions. In our system, tenure, rank, and salary scales have essentially a one-to-one correspondence and, thus, high salary is usually obtained by appointing at a high rank.

Some of these problems were discussed in a report by R. Bressler to Chancellor Strong in November 1961; although he was aware of the many variables that influence the salary levels, age distribution, and stability of tenure and nontenure ranks, he was primarily concerned with a suitable means for increasing nontenure lifetimes. To do this, he proposed the addition of Step IV at the Assistant and Full Professor levels along with new salary scales to ensure the success of his recommendations.

On several occasions in 1965 Clark Kerr again raised the issue of large proportions of budgeted positions occupied by tenure faculty at a time when increases in new budgets were becoming more difficult to obtain. Even at that time the highest proportion of tenure appointments existed at the Berkeley and San Diego campuses and predictions were that the age and fraction of tenure faculty would rise sharply as the growth rate in these campuses stabilized.

Perhaps a more basic reason for making a mathematical study of the underlying structure of the appointment, promotion and retirement system is the desire to understand and predict, in a quantitative way, what effect various operating policies, long-run goals and restrictions can have on the size, distribution and age of faculty ranks in a large university. Even though large proportions of tenure faculty may create no serious problems whatsoever, it is our hope that such an analysis will give insight and, by suggestion of alternative policies, forestall certain difficulties before they arise.

2. A Summary of Findings

In this section I would like to summarize some of the results that can be obtained from the body of the report.

(1) Conservation requirements that must hold for appointment, promotion and attrition of faculty and quota restrictions on the total number of faculty severely restrict the choice of independent variables. That is to say, the rate and mixture of new appointments, the rate of promotions to tenure and retirements from tenure must stay within prescribed bounds and observe known relationships if equilibrium levels are to be achieved. Graphs showing feasible operating regions based on Berkeley campus data are shown in Figures (4), (5) and (6).

(2) Extrapolation of current Berkeley data to the years 1975-1980 when we expect equilibrium to set in indicates that there exist no feasible equilibria for current appointment policies. Even if retirement rates are twice the predicted values for that period, fractional promotion rates from nontenure would have to drop to one-sixth of their current values. These results are discussed on Page 33 and shown in Figures (4) and (6).

(3) If either the new appointment or retirement rates were adjusted sufficiently to bring other variables within feasible operating regions it appears that the equilibrium points characterizing Berkeley campus operations lie on or close to the boundaries of the feasible regions. In other words, small fluctuations could quickly take us from a feasible to an infeasible point. See the discussion on Pages 32 - 35.

(4) Since resignation rates for nontenure faculty are significantly higher than those for tenure faculty on the Berkeley campus (Tables (1), (2) and (3)) *increased rates of new appointments to tenure will always reduce the equilibrium number of tenure faculty*. This surprising result is discussed on Page 36.

(5) Operating policies which are infeasible by virtue of too small a rate of new appointments to nontenure or tenure cannot be made feasible by increasing retirement rates. On the other hand, infeasible policies due to very large appointment rates can be made feasible by increasing retirement and reducing promotion rates. See Pages 16 and 31 - 33.

(6) The introduction of minimum levels on nontenure faculty reduces the region of feasible appointment and retirement rates; in particular, increasing the nontenure fraction makes those equilibrium values corresponding to *small* nontenure appointment rates infeasible. See Figure (3) and the discussion on Pages 17 - 19.

(7) It is possible to compute critical values for maximum promotion rates and minimum equilibrium levels of nontenure faculty such that restrictions of the latter type are completely compatible with restrictions of the former type. Restrictions of the former type can *never* be completely subsumed by the latter. See Pages 17 - 19 and Figure (3).

(8) Examination of data for the Berkeley campus during the years 1955-1967 indicates reasonable stability in certain attrition and promotion rates. See Table 3 and the discussion following Page 25.

(9) It is possible to predict the effects of new appointment, promotion and retirement policies on the level and mix of faculty and on the flow rates which enter and leave the system.

3. Contents of this Report

Quota restrictions on the total number of budgeted faculty positions and the simple conservation requirements that must hold for the attrition of faculty in all ranks plus the transfers between nontenure and tenure ranks makes it possible for us to obtain explicit relations between the distribution of faculty by rank and the number of new appointments into the system. Thus, it is possible to formulate a reasonably simple equilibrium model as a function of appointment policies, resignation, promotion, and retirement rates, and quotas on the total number of budgeted positions. The effects of quota restrictions are not as obvious as one might expect. They establish a connection between the numbers of tenure and nontenure faculty and, hence, between their ratios; unless the relative magnitude and effects of various attrition rates are studied, it is not clear whether new appointments to these two groups of faculty will increase or decrease the relative fraction of tenure appointments or how their age distribution will be affected.

This report is the first of several dealing with long-range implications of faculty appointments, promotions, and retirement policies. Here, we focus attention on simple models in which quotas and flow rates are unchanging with time. Equilibrium has set in and the questions that are discussed are how the equilibrium values vary as a function of the appointment policies and attrition rates. Another report will consider salary and budgeting implications, while still another will consider the effects of time-dependent appointment, promotion, and retirement policies which are now of increasing importance on this and other campuses. A fourth report will focus attention on the effect of new retirement policies on the distribution of tenure and nontenure faculty.

Section II.1 of this report formulates a simple deterministic model of faculty appointments, promotions and resignations in the presence of quota restrictions. This is followed by two sections discussing regions of feasible operating policies. A fourth section shows the effect of assuming linear transfer rates, in other words those cases where promotion and retirement rates are linearly dependent on the number of tenure or nontenure faculty.

In Sections III.1 and III.2 we are specifically concerned with forecasting equilibrium conditions at the Berkeley campus of the University of California for different types of operating policies. Parameters used in the model are derived from campus data in the periods 1955-1960 and 1963-1967. Finally, an attempt is made to predict the quantitative effects of schedule changes, retirement and appointment policies and new types of quotas.

It was my original intent to briefly summarize results we have obtained during the past year and leave mathematical details to a paper published at a later time. This approach seems artificial since the results we discuss depend on the assumptions that are made; it is quite possible that a reader of this report might want to add, relax, or modify constraints and assumptions and then look at the values of new equilibria predicted by the model. For this reason I have decided to include some of the mathematical arguments although a reader uninterested in these details can read the text and still obtain a qualitative feeling for the structure of solutions.

II. A THREE-STAGE EQUILIBRIUM MODEL

1. Dependent and Independent Variables

A natural and simple way of characterizing the major components of faculty appointments is in terms of the nontenure, tenure, and retired faculty members. At an earlier stage of our development the retired faculty members would not have played an important part in a discussion of the active members but this is no longer the case. Consider the diagram in Figure (1) which has three stages corresponding to nontenure, tenure, and retired faculty members. In equilibrium, the number of faculty in these stages are respectively denoted by N_1, N_2 and N_3. In the problems we are about to study, we assume a quota restriction on active faculty members, i.e.,

$$N_1 + N_2 = N; \qquad N_3 \text{ unrestricted} \tag{1}$$

where N is given and fixed. The new appointment rates (people per time period) are given by λ_1 and λ_2; the rates θ_1 and θ_2 denote the number of transfers between stages per time period. In the case of the first stage, these transfers correspond to promotions from nontenure to tenure while they represent retirements from tenure in the case of the second stage. It is assumed that there are no transfers or promotions into nontenure just as there are no new appointments into the retirement stage; to put it another way, the tenure positions are the only ones into which there are both new appointments, promotions from a lower stage, and retirements. We allow for the possibility of resignations and deaths by specifying fractional attrition rates μ_1, μ_2, and μ_3 for each stage. These latter rates, as distinct from λ's or θ's have the dimensions of number of people resigning per unit time per number of people in each state; in other words, the flow rates for people leaving the system by resignation or death are

$$\mu_1 N_1, \ \mu_2 N_2 \quad \text{and} \quad \mu_3 N_3 .$$

In equilibrium the number entering and leaving each state must balance; we express these conditions mathematically by writing:

$$\lambda_1 = \mu_1 N_1 + \theta_1 \tag{2.a}$$

$$\lambda_2 + \theta_1 = \mu_2 N_2 + \theta_2 \tag{2.b}$$

$$\theta_2 = \mu_3 N_3 . \tag{2.c}$$

These conservation equations and the quota restrictions of (1) impose constraints on the manner in which the University system can operate and the equilibrium rate at which new appointments can be made. One can also visualize them as imposing constraints on circulation flows where the positions released by resignations, deaths and retirements are equal to the rate of new appointments. In other words, we could write another conservation equation

$$\lambda_1 + \lambda_2 = \mu_1 N_1 + \mu_2 N_2 + \theta_2 \tag{3}$$

but since it is the sum of Equations (2.a,b) we will not make explicit use of it in our analysis.

Many of the quantities in Equations (1) and (2) must be restricted to nonnegative values. For example we require nonnegative faculty levels

$$N_1 \geq 0 \qquad N_2 \geq 0 \qquad N_3 \geq 0 \tag{4.a}$$

and we require that promotions to tenure and retirements from tenure flow in the direction of the arrows in Figure 1, i.e., that

$$\theta_1 \geq 0 \qquad \theta_2 \geq 0 . \tag{4.b}$$

As we will see in the following sections of this report the inequalities of (4.a) are equivalent to upper bound constraints on certain flow rates.

Additional quota restrictions and minimum bounds on transfer rates are frequently imposed. For example, if nontenure appointments are not to be less than a given fraction α of the total quota we write

$$N_1 \geq \alpha N \ , \tag{4.c}$$

if promotion rates from nontenure to tenure are to be no smaller than a fraction β of all new appointments to tenure we write

$$\theta_1 \geq \frac{\beta}{1-\beta} \lambda_2 \ . \tag{4.d}$$

Finally, a third restriction that might be required is that new appointments from external sources be no less than a specified fraction γ of all new appointments,

$$(\lambda_1 + \lambda_2) \geq \frac{\gamma}{1-\gamma} \theta_1 \ . \tag{4.e}$$

A simple count of the number of known and unknown quantities in Equations (1) and (2) illustrates the degrees of freedom that are available. We have four independent equations and the count of known and unknown quantities might be as follows

$$N, \mu_1, \mu_2, \mu_3 \text{ given}, \tag{5.a}$$

$$\theta_1, \theta_2, N_1, N_2, N_3, \lambda_1, \lambda_2 \text{ to be found.} \tag{5.b}$$

In this case elmination of four of the variables in (5.b) via Equations (1) and (2) allows us to specify them in terms of any three independent variables. For example, if new appointments and retirement rates are specified as the independent variables we obtain

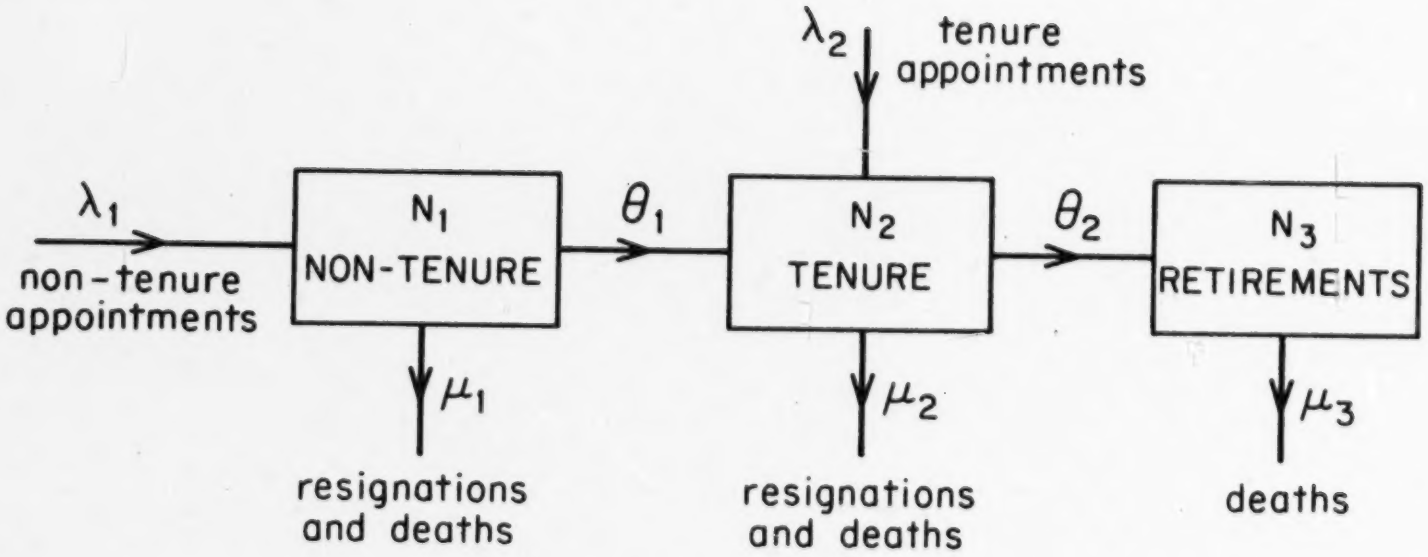

FIG. 1 FACULTY APPOINTMENTS, PROMOTIONS, RETIREMENTS AND RESIGNATIONS

$$\theta_1 = \theta_1(\lambda_1,\lambda_2,\theta_2);\ N_1 = N_1(\lambda_1,\lambda_2,\theta_2);$$

$$N_2 = N_2(\lambda_1,\lambda_2,\theta_2);\ N_3 = N_3(\lambda_1,\lambda_2,\theta_2)\ .$$

If the equality of (4.c) were imposed, there would be five independent equations and seven unknowns. In this case, two could be specified independently; if we chose to make promotion and retirement rates the independent variables then

$$N_3 = N_3(\theta_1,\theta_2);\ \lambda_1 = \lambda_1(\theta_1,\theta_2);\ \lambda_2 = \lambda_2(\theta_1,\theta_2) \quad \text{etc.}$$

Equations (1) and (2) and the inequalities of (4) by no means exhaust the types of restrictions that a university faculty and administration can impose upon themselves, but it should be clear that they cannot arbitrarily specify all variables independently. A choice of new appointment and retirement rates influences numbers at tenure and nontenure levels which affect attritions. These, in turn, affect appointment and retirement policies. It is the purpose of the remaining sections of this report to examine operating policies that are dictated by feasible solutions of some of the constraints we have just mentioned. We are especially concerned with an understanding of the conditions which lead to the boundaries of these regions not so much because they may represent desireable equilibria but because they provide a simple and meaningful way to realistically compare the behavior of different appointment, promotion and retirement policies.

2. Feasible Operating Policies

It may help to illustrate these ideas by working out the details of the case where we specify appointment and retirement rates as the independent variables. In other words a choice of λ_1, λ_2 and θ_2 specify all other unknowns in the three-stage equilibrium model. The promotion rate is obtained by substituting Equations (2.a) and (2.b) into (1).

$$\frac{\lambda_1 - \theta_1}{\mu_1} + \frac{\lambda_2 - \theta_2 + \theta_1}{\mu_2} = N \tag{6}$$

or,

$$\theta_1 = [\mu_1 \mu_2 N - \mu_2 \lambda_1 - \mu_1 \lambda_2 + \mu_1 \theta_2](\mu_1 - \mu_2)^{-1} . \tag{7.a}$$

When the fractional resignation and death rate of nontenure exceeds that of tenure, the promotion rate from nontenure to tenure is a linearly decreasing function of the sum of new appointment rates. The equilibrium levels of faculty are then

$$N_1 = [\lambda_1 + \lambda_2 - \theta_2) - \mu_2 N](\mu_1 - \mu_2)^{-1} \tag{7.b}$$

$$N_2 = [\mu_1 N - (\lambda_1 + \lambda_2 - \theta_2)](\mu_1 - \mu_2)^{-1} \tag{7.c}$$

while the number of retired faculty is

$$N_3 = \theta_2 \mu_3^{-1} . \tag{7.d}$$

We are now in a position to discuss feasible regions for λ_1, λ_2 and θ_2. Appointment rates are nonnegative and we know that the inequalities of (4.a,b) must hold. A nonnegative faculty level in the nontenure ranks implies that the promotion rate to tenure must be less than or equal to the appointment rate of new nontenure

faculty,

$$0 \leq \theta_1 \leq \lambda_1 \ . \tag{8.a}$$

When the right hand equality of (8.a) holds and the rate of promotions equals the new appointment rate, we have $N_1 = 0$ and

$$\lambda_1 + \lambda_2 = \mu_2 N + \theta_2 \ . \tag{8.b}$$

In this case all faculty leave the system as tenure faculty; while it may appear that the role of nontenure appointments has become somewhat artificial one can think of it as a limiting example of the behavior to expect when μ_1 is small or nontenure lifetimes are large.

$\theta_1 = \lambda_1$ corresponds to the left edge of Figure (2); Equation (7.a) indicates that constant values of θ_1 correspond to straight lines pivoted about the point $\lambda_1 = 0$, $\lambda_2 = N \mu_2 + \theta_2$. If the line is rotated in a counterclockwise direction θ_1 decreases until finally θ 0 and there are two independently operating academic units in the sense that nontenure faculty are appointed to tenure positions. In this extreme case feasible operating policies are represented by combinations of new appointment rates that satisfy

$$\lambda_2 + \mu_2 \mu_1^{-1} \lambda_1 = \mu_2 N + \theta_2 \ . \tag{8.c}$$

Equation (8.c) is similar to (8.b) except that the slope of the straight line in the λ_1, λ_2 plane is $-\mu_2 \mu_1^{-1} > -1$. The $\theta_1 = 0$ line corresponds to the top right edge of Figure (2); any point on this line establishes a nontenure faculty appointment rate $\lambda_1 = \mu_1 N_1$ and a tenure faculty appointment rate $\lambda_2 = \mu_2(N - N_1) + \theta_2$. Specification of a retirement rate θ_2 and a fractional split between nontenure and tenure is then sufficient to uniquely determine the new appointment rates into both categories.

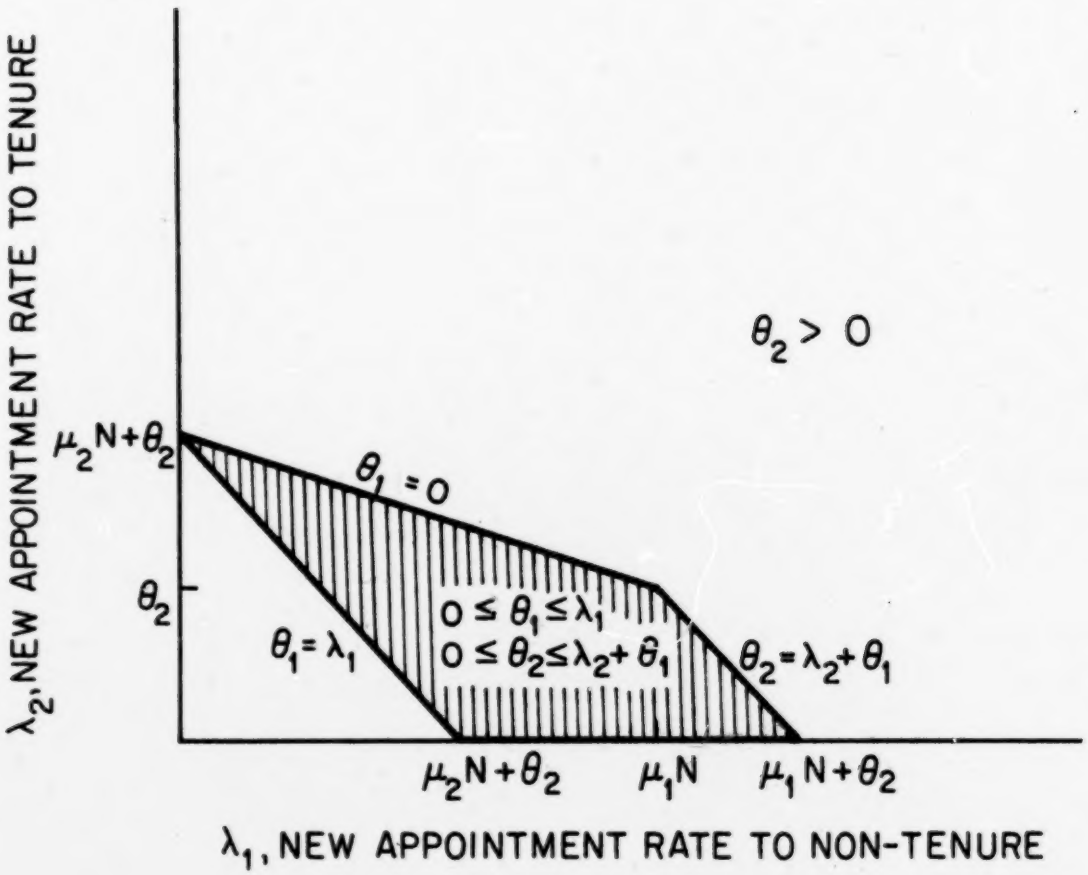

FIG. 2 THE REGION OF FEASIBLE NEW APPOINTMENT AND RETIREMENT RATES.

Feasible values of the retirement rate can be obtained in a similar manner. Clearly, θ_2 must be nonnegative. When $\theta_2 = 0$ all tenure faculty leave the system by death or resignation as there are no retirements. On the other hand, the retirement rate cannot be larger than the total input rate to tenure and thus must observe the inequality,

$$0 \leq \theta_2 \leq \theta_1 + \lambda_2 \,. \tag{9}$$

Notice that unless we want to include additional restrictions on the total rates of new appointments there is no priori reason why the number of faculty in retirement cannot be arbitrarily large. When the right hand equality in (9) holds the input rate to tenure from nontenure and external sources just equals the retirement rate. As a result there are no resignations from tenure, the size of the tenure faculty is zero and the nontenure size equals the quota N. In this case, operating policies for λ_1 and λ_2 correspond to the right hand edge of Figure (2); feasible values of θ_2 lie on or to the left of this edge parallel to the $\theta_1 = \lambda_1$ line we discussed earlier. We can summarize the feasible regions of Figure (2) in the following way: an equilibrium point moving from left to right moves from values of low nontenure levels to high nontenure levels. An equilibrium point at the top of the shaded region represents a condition under which there is little connection between the tenure and nontenure faculty in the sense that there are few promotions. A point near the bottom edge may or may not correspond to large promotion rates but in any case all tenure appointments have been appointed from nontenure ranks.

Figure (2) is, in reality, a projection in the (λ_1, λ_2) plane of a three dimensional feasible region for the independent variables λ_1, λ_2 and θ_2. A projection in the (θ_2, λ_1) or the (θ_2, λ_2) planes for a fixed value of

λ_1 will result in feasible regions similar to those shown in Figure (5).

In Figure (2) we assumed that θ_2 was fixed. Increases in θ_2 slide the shaded figure away from the origin and increase *both the number and values of feasible new appointment rates.* Notice that an equilibrium point (i.e., a choice of λ_1, λ_2) which is infeasible because it lies to the left of the shaded area cannot be made a feasible equilibrium point by increasing the retirement rate. Rather it is an equilibrium point which lies above the $\theta_1 = 0$ line or to the right of the $\theta_2 = \lambda_2 + \theta_1$ line that can be brought into the feasible region by increasing the retirement rate. We will study the implications of this effect more carefully in Section III when we consider data for the Berkeley campus.

3. Nontenure Constraints and Restricted Promotions

In this section we study the effect of minimum nontenure constraints such as Equation (4.c) and maximum promotion rates from nontenure to tenure. A restriction of the form $N_1 = \alpha N$ removes one degree of freedom; in conjunction with the conservation equations we now have

$$\lambda_1 = \mu_1 \alpha N + \theta_1 ,$$

$$\lambda_2 + \theta_1 = \mu_2(1 - \alpha)N + \theta_2 ,$$

$$\theta_2 = \mu_3 N_3 .$$

Notice that the quota restriction is automatically satisfied and, we do not need to restate Equation (1). Eliminating θ_1 from these equations or subsituting α in Equation (3) gives the result

$$\lambda_2 + \lambda_1 = [\mu_1 \alpha + \mu_2(1 - \alpha)]N + \theta_2, \qquad 0 \leq \theta_2 < \infty \tag{10.a}$$

which for fixed θ_2 is a straight line in the (λ_1, λ_2) plane with slope -1 and intercepts equal to a hypothetical resignation rate $\mu' = (\mu_1\alpha + \mu_2(1 - \alpha))$ times the quota N. It is interesting that this hypothetical resignation rate lies between the two extremes of tenure and nontenure resignation rates. Thus the right-hand side of (10) lies between the two intercepts of the λ_1 axis in Figure (2).

The geometric effect of the inequality constraint on nontenure faculty is to reduce the region of feasible values in the (λ_1, λ_2) plane. Draw a straight line parallel to and to the right of the boundary line corresponding to $\theta_1 = \lambda_1$, $N_1 = 0$. Recall that this corresponds to the physical situation where all faculty are in the tenure ranks even though a sizeable fraction are

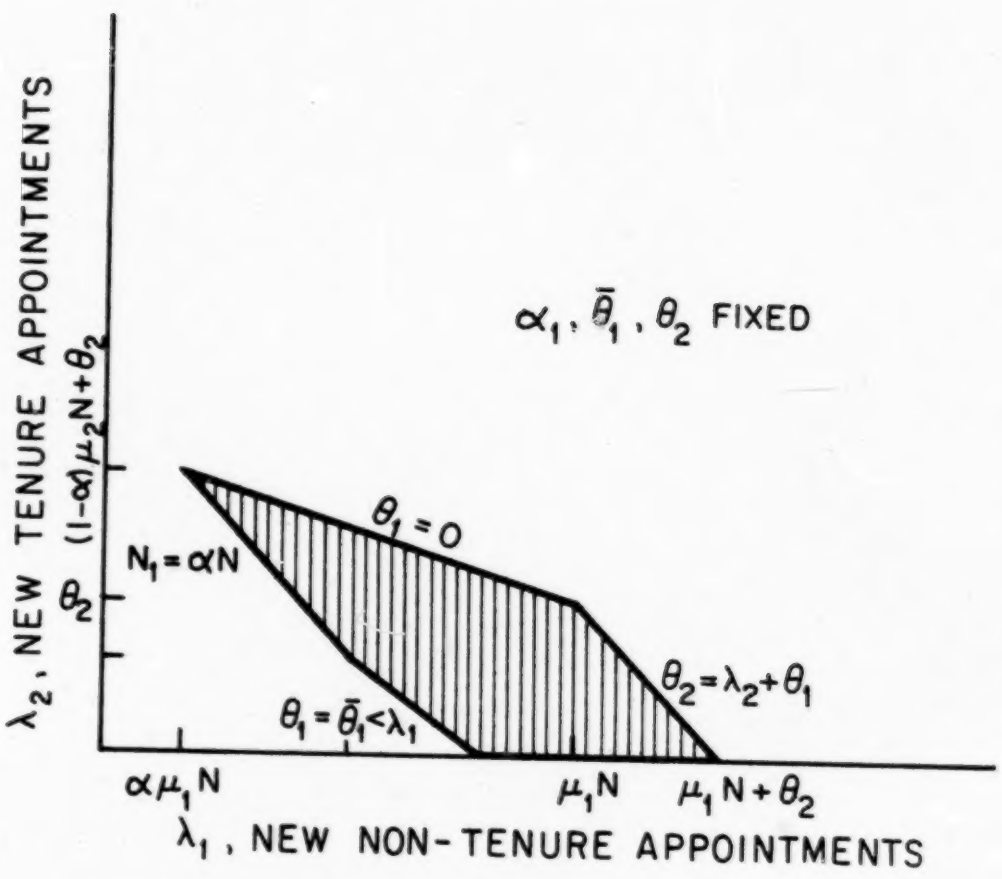

FIG. 3 EFFECT OF TENURE CONSTRAINTS WITH RESTRICTED PROMOTIONS.

appointed at nontenure and quickly promoted to tenure. Points that satisfy $N_1 > \alpha N$, i.e., the strict inequality, lie to the right of this line and thus lead to a smaller shaded area whose left hand edge is parallel to and between the left and right hand edges of Figure (2).

An upper bound on the promotion rate θ_1 , say $\theta_1 \leq \bar{\theta}_1$, will also lead to a reduction in the area of the feasible region but, for reasons that we will explain, this region may already be excluded by the minimum nontenure constraint. As we have already mentioned, a decrease in θ_1 corresponds to a line pivoted about the upper left corner of Figure (2) that rotates in a counterclockwise direction. Hence the feasible region removed by such a promotion constraint operating independently of a nontenure constraint, is a triangle with left edge corresponding to the $\theta_1 = \lambda_1$ line. If minimum nontenure fractions α are larger than the critical value,

$$\bar{\alpha} = 1 - (\bar{\theta}_1 - \theta_2)(\mu_2 N)^{-1} \qquad (10.b)$$

then the right hand edge of this triangle lies wholly within the infeasible region removed by the nontenure constraint. In other words when $\alpha > \bar{\alpha}$ the constraint on promotion rates has no effect. On the other hand, any $\alpha > 0$ reduces the region of feasible appointment rates for a given $\bar{\theta}_1$.

The relation of these constraints is shown in Figure (3) when $\alpha < \bar{\alpha}$. Notice that the constraint on promotion rates tends to remove a region for which small λ_1 and λ_2 values were originally feasible while the nontenure constraint removes regions for which larger values of λ_2 were feasible.

4. Linear Promotion and Retirement Rates

Although we have been careful to avoid excessively restrictive assumptions on the transfer rates θ_1 and θ_2 it is not unreasonable to assume that they are linearly proportional to the number of nontenure and tenure faculty respectively. This type of assumption has already been made by several chancellors and administrative officers in their study of attrition rates on other campuses of the university. To study the effect of such assumptions we write

$$\theta_1 = \phi_1 N_1; \qquad \theta_2 = \phi_2 N_2 \tag{11.a,b}$$

where ϕ_1 and ϕ_2 are known and given. ϕ_1 and ϕ_2 have the same dimensions as μ_1, μ_2, μ_3 in order that θ_1, θ_2 be flow rates. The number of degrees of freedom in the three-stage model now reduces to one since the given parameters are

$$N, \mu_1, \mu_2, \mu_3, \phi_1, \phi_2$$

and the unknowns are

$$N_1, N_2, N_3, \lambda_1, \lambda_2 .$$

Equations (1) and (2) allow us to eliminate any four of the five variables. In terms of our earlier notation we now define average lifetimes in nontenure, tenure ranks and in retirement by

$$\tau_N = (\mu_1 + \phi_1)^{-1} \tag{12.a}$$

$$\tau_T = (\mu_2 + \phi_2)^{-1} \tag{12.b}$$

$$\tau_R = \mu_3^{-1} . \tag{12.c}$$

If we choose λ_1 as the independent variable the nontenure level is

$$N_1 = \lambda_1(\mu_1 + \phi_1)^{-1} = \lambda_1 \tau_N \,. \tag{13.a}$$

Similarly,

$$N_2 = (\lambda_2 + \phi_1 \lambda_1 \tau_N) \tau_T = N - \lambda_1 \tau_N \,. \tag{13.b}$$

The terms in parenthesis can be interpreted as an overall input rate of tenure faculty. Multiplying this rate by the average lifetime $\tau_T = (\mu_2 + \phi_2)^{-1}$ gives the number of tenure appointments. The number in retirement,

$$N_3 = \phi_2 N_2 \mu_3^{-1} = \phi_2(N - \lambda_1 \tau_N) \tau_R \,, \tag{13.c}$$

is just equal to the retirement input rate times the mean lifetime $\tau_R = \mu_3^{-1}$ in the retirement system. Finally, the input rate to tenure levels must be

$$\begin{aligned} \lambda_2 &= (\mu_2 + \phi_2)N - \frac{\mu_2 + \phi_1 + \phi_2}{\mu_1 + \phi_1} \lambda_1 \\ &= \frac{N - \lambda_1 \tau_N}{\tau_T} - \phi_1 \lambda_1 \tau_N \end{aligned} \tag{13.d}$$

if we are to maintain the levels of (13.a,b) in equilibrium. As we might expect, the flow of new tenure appointments decreases linearly with increased rates of new tenure appointments. The reason is simply that the linearity assumption on promotions guarantees us an increase in promotions and nontenure faculty whenever nontenure appointments increase. Since we know that tenure appointments must decrease to maintain quotas, this can only be achieved by reducing new appointments to tenure. On the other hand, if the rate of new tenure appointments is the independent variable for which we pick a desireable equilibrium value, we obtain

$$\lambda_1 = \frac{(\mu_1 + \phi_1)(\mu_2 + \phi_2)N}{\mu_2 + \phi_1 + \phi_2} - \frac{(\mu_1 + \phi_1)\,\lambda_2}{\mu_2 + \phi_1 + \phi_2} \tag{14.a}$$

$$N_1 = \frac{(\lambda_2 + \phi_2)N}{\mu_2 + \phi_1 + \phi_2} - \frac{\lambda_2}{\mu_2 + \phi_1 + \phi_2} \tag{14.b}$$

and a nontenure ratio,

$$\frac{N_1}{N} = \frac{\mu_2 + \phi_2}{\mu_2 + \phi_1 + \phi_2} - \frac{\lambda_2}{N(\mu_2 + \phi_1 + \phi_2)} \quad . \tag{14.c}$$

In all cases that we consider in this report the resignation rate of nontenure faculty far exceeds that of tenure, i.e., $\mu_1 \gg \mu_2$, and even exceeds the total attrition rate from tenure, i.e., $\mu_1 > \mu_2 + \phi_2$. This inequality accounts for the large differences between long tenure lifetimes and short nontenure lifetimes.

An analysis of the appointment policies in Equations (13) or (14) is now a simple matter. We first consider the intercepts and slope of Equation (13.d) or (14.b). The intersection of the λ_2 axis occurs at N/τ_T , i.e., a flow rate required to keep the quota in tenure ranks. Hence the straight line, expressing tenure appointments in terms of nontenure, pivots about this point and has a slope determined by the coefficient of λ_1 in (13.d). The inequality

$$\frac{\mu_2 + \phi_1 + \phi_2}{\mu_1 + \phi_1} > \frac{\tau_N}{\tau_T} \tag{15.a}$$

is always observed; thus by multiplying both sides by -1 we see that the slope is always less than that of a straight line intersecting the λ_1 axis at N/τ_N and the λ_2 axis at N/τ_T . To put it another way the λ_1 intercept of Equation (13.d) lies to the left of N/τ_N because we have

$$\lambda_1 = \frac{N}{\tau_N}\left(1 + \phi_1 \tau_T\right)^{-1} < \frac{N}{\tau_N} \qquad (15.b)$$

whenever ϕ_1 is positive and $\lambda_2 = 0$. To show that this intercept also lies to the right of N/τ_T and hence that the slope is greater than -1 we simply rewrite the left-hand side of (15.b) in the form

$$\lambda_1 = \frac{N}{\tau_T}\frac{\phi_1 + \mu_1}{\phi_1 + \phi_2 + \mu_2} > \frac{N}{\tau_T} . \qquad (15.c)$$

The strict inequality in (15.c) holds whenever $\mu_1 > \phi_2 + \mu_2$, a condition we mentioned earlier and will discuss in some detail in the next section.

A nontenure restriction of the form $N_1 = \alpha N$ imposes a linear relation between λ_1 and λ_2 independently of either Equation (13.d) or (14.a); more specifically it is a straight line in the (λ_1, λ_2) plane parallel to the line representing those solutions where all nontenure faculty are promoted to tenure. Two cases occur: either (i) the equations $N_1 = \alpha N$ and (13.d) are incompatibale in which case no solution exists or (ii) they predict a unique solution such that

$$\lambda_1 = (\mu_1 + \phi_1) N \qquad (16.a)$$

$$\lambda_2 = ((1 - \alpha)(\mu_2 + \phi_2) - \alpha\phi_1) N . \qquad (16.b)$$

The fraction α has to be a number less than or equal to

$$\bar{\alpha} = \frac{\mu_2 + \phi_2}{\phi_1 + \mu_2 + \phi_2}$$

for the solution of (16) to exist. If α is greater than $\bar{\alpha}$ then Equations (13.d) and $N_1 = \alpha N$ have no common intersection for $\lambda_1, \lambda_2 \geq 0$ and case (i) holds. That is to say, the restrictions $N_1 \geq \alpha N$ and the linearity assumption are incompatible.

III. THE BERKELEY CAMPUS

1. Data and their Sources

In order to obtain estimates for attrition, promotion and retirement rates that we use in our models we refer to Tables (1), (2) and (4), into which the data has been organized. They have been collected from three sources: (1) A special report to Chancellor Strong entitled, "Promotion Schedules and Salary Scales," authored by R. G. Bressler November 10, 1961; (2) A report by President Clark Kerr to members of the Committee on Finance and on Educational Policy dated May 12, 1965; and (3) Faculty data cards which have been made available to us by the Chancellors office at the Berkeley Campus of the University of California.

Our data covers essentially two nonoverlapping periods 1955-1960 and 1963-1967. Some of the statistical information that we use for the 1955-1960 period is summarized in Bressler's report. Kerr's report covers a period from 1960-1964 which we do not duplicate here; however, we do make use of his retirement projections for the period 1964-1969 that partially overlaps our own data collected from campus sources.

Although Bressler's original data included instructors in a count of nontenure faculty we do not. Thus our definition of nontenure includes Assistant Professors, regular, acting and clinical. Tenure faculty includes Associate and Full Professors and Full Professors that are at over-scale steps. Although acting Associate Professors can be classified as nontenure faculty we have chosen to show a conversion from lecturer or acting status to regular Associate or Full Professor as a new appointment rather than a promotion. The numbers in this category are small and should not have a major effect on promotion rates if readers of this report disagree with this convention and wish to include them in the promotion data.

We have made every effort to obtain consistent data in the sense that increases or reductions in any given category of faculty are made during a period just before or just after faculty counts are made. With few exceptions the inventory of faculty is made on July 1st, i.e., the beginning of a fiscal and academic year. We have also computed balance sheets (not reported here) to ensure that the inventory of staff at the beginning of one period minus deletions plus additions equals the actual inventory at the end of that period. Surprisingly enough, we have never been able to make these figures agree exactly but after four months of tedious and exhaustive search through only partially complete data we have reached the point where independent inventory counts never disagree by more than two or three faculty members; thus our counts should be in error by no more than 3/4 of a percent for nontenure and by no more than 1/4 of a percent for tenure faculty.

Table (3) is a list of fractional resignation, promotion and retirement data computed from Tables (1) and (2). One must be aware of the errors to which such gross estimates can sometimes lead. For example, time lags may play an important role in the sense that attritions in one year may be more closely related to faculty levels four or five years prior rather than to levels of the preceding year. There are definite time-varying trends in the data we have gathered; calculation of the entries in Table (3) leads, at best, to order of magnitude estimates for parameters in our model. Nonetheless, we calculate these parameters in order to make valid comparisons with attrition and promotion rates reported elsewhere.

The fractional resignation rates for tenure and nontenure faculty agree well with figures quoted on Page 14 of the Kerr report. During 1960-1964 he obtains a figure of 1.5% for a four year average of statewide resignations from

TABLE 1: NONTENURE PROMOTIONS AND RESIGNATIONS

Year	Nontenure[a]	Promoted to Tenure	Resignations and Deaths
1955-1956	245	37	48
1956-1957	237	33	44
1957-1958	254	35	37
1958-1959	275	34	54
1959-1960	263	52	34
1963-1964	353	24	41
1964-1965	388	41	50
1965-1966	429	48	63
1966-1967	456	58	44

(a) Includes Assistant Professors: regular, acting and clinical.

TABLE 2: TENURE RETIREMENTS AND RESIGNATIONS

Year	Tenure[(a)]	Retirements	Resignations and Deaths
1963-1964	927	8	5
1964-1965	958	13	32
1965-1966	981	9	32
1966-1967	1013	14	24

(a) Includes Associate, Full Professors and Full Professors over scale, but not Lecturers or Acting Titles in these ranks.

TABLE 3: PROMOTION AND ATTRITION RATES

Year	Nontenure		Tenure	
	μ_1	ϕ_1	μ_2	ϕ_2
1955-56	.196	.151	-	-
1956-57	.186	.139	-	-
1957-58	.146	.138	-	-
1958-59	.196	.124	-	-
1959-60	.129	.198	-	-
1963-64	.116	.068	.005	.009
1964-65	.129	.106	.033	.014
1965-66	.147	.112	.033	.009
1966-67	.096	.127	.024	.014

tenure and 12.5% for resignations from nontenure. Fractional retirement rates during this same period averaged 1.3% of tenure faculty per year. The best agreement between Table (3) and Kerr's figures occur for μ_1 and ϕ_2. Our μ_2 differs by a factor of two possibly for the reason that his tenure faculty count includes acting titles in tenure ranks which ours do not. An inequality which we required frequently in the linear models of II.4 is

$$\mu_1 > \phi_2 + \mu_2 .$$

Oberve that this inequality is in fact observed for entries in Table (3). Resignation rates decrease as the seniority and rank of the appointment increases. This implies, in our models, that $\mu_1 > \mu_2$. This tendency is particularly well documented in the Kerr report which quotes average fractional rates of 0.7% among Full Professors, 2.0% among Associate Professors, 10% among Assistant Professors, and 40.5% among Instructors.

Table (5) is obtained from Table (3) and the defining expressions for nontenure and tenure lifetimes in (12.a,b). Since lifetimes are the reciprocal of fractional flow rates with per annum dimensions, they in turn have the dimensions of years. Clearly tenure lifetimes are several times larger than nontenure. Typically a new appointment into nontenure ranks will stay for an average of five years; those who do not resign average ten years. This service period is followed by approximately twenty five years in tenure; for those who stay at Berkeley until retirement this figure is increased to thirty years. Thus a man appointed at age twenty five that retires at age sixty-five has approximately one fourth of his service in nontenure ranks.

TABLE 4: NEW APPOINTMENTS

Year	Nontenure, $\lambda_1^{(a)}$	Tenure, $\lambda_2^{(b)}$
1955-1956	21	14
1956-1957	39	14
1957-1958	77	44
1958-1959	66	39
1959-1960	64	24
1963-1964	101	20
1964-1965	131	25
1965-1966	139	23
1966-1967	135	40

(a) Nontenure includes Acting Assistant, Clinical Assistant and Assistant Professor

(b) New appointments to tenure include conversions from Lecturer and Acting Associate Professors.

TABLE 5: SERVICE LIFETIMES IN NONTENURE AND TENURE RANKS

Year	$\tau_1 = \mu_1^{-1}$	$\tau_2 = \mu_2^{-1}$	$\tau_N = (\mu_1 + \phi_1)^{-1}$ (Nontenure)	$\tau_T = (\mu_2 + \phi_2)^{-1}$ (Tenure)
1955-56	5.10	-	2.88	-
1956-57	5.39	-	3.08	-
1957-58	6.87	-	3.53	-
1958-59	5.09	-	3.13	-
1959-60	7.74	-	3.06	-
1963-64	8.61	200.00	5.43	71.43
1964-65	7.75	30.30	4.26	21.28
1965-66	6.80	30.30	3.86	23.71
1966-67	10.42	41.67	4.48	26.32

2. Equilibria and the Effects of Changes in Service Lifetimes, Promotions and Retirement Policies

A simple way of understanding how parameters in our models influence faculty levels, promotions and appointment policies can be obtained by studying hypothetical situations. Before we do this we use some of the data collected in the previous section to obtain graphs of the feasible regions for appointment and retirement policies on the Berkeley campus. In those cases where we use the linear models in Section II.4 we assume

$$N = 1500 \qquad \alpha = 0.33$$

$$\mu_1 = 0.097 \qquad \phi_1 = 0.127$$

$$\mu_2 = 0.024 \qquad \phi_2 = 0.014$$

These numbers correspond to the last row of Tables (1) - (4), i.e., the academic year 1966-1967. When we refer to the models in II.2 the data for α, ϕ_1 and ϕ_2 is not used. Figure (4a) indicates the feasible new appointment policies when the retirement rate θ_2 is assumed to be twenty faculty members per year and the quota, N, equals 1500. In (4b) the quota has increased to 1800, all other parameters being kept constant and in (4c) the retirement rate is increased to fifty faculty per year. While the area of the entire feasible region increases as we move from Figure (4a) to (4c) the infeasible region in the bottom left corner also increases because retirements increase and faculty quotas can only be met by larger and larger new appointment rates. This exclusion of feasible appointment rates was mentioned at the end of Section II.2. The two values of θ_2 chosen for Figure (4) roughly correspond to the numbers predicted by Bressler and Kerr for the period 1965-1970 ($\theta_2 = 20$ retirements per year); in addition Bressler predicted 45 or more retirements per year after 1980. Forecasts for

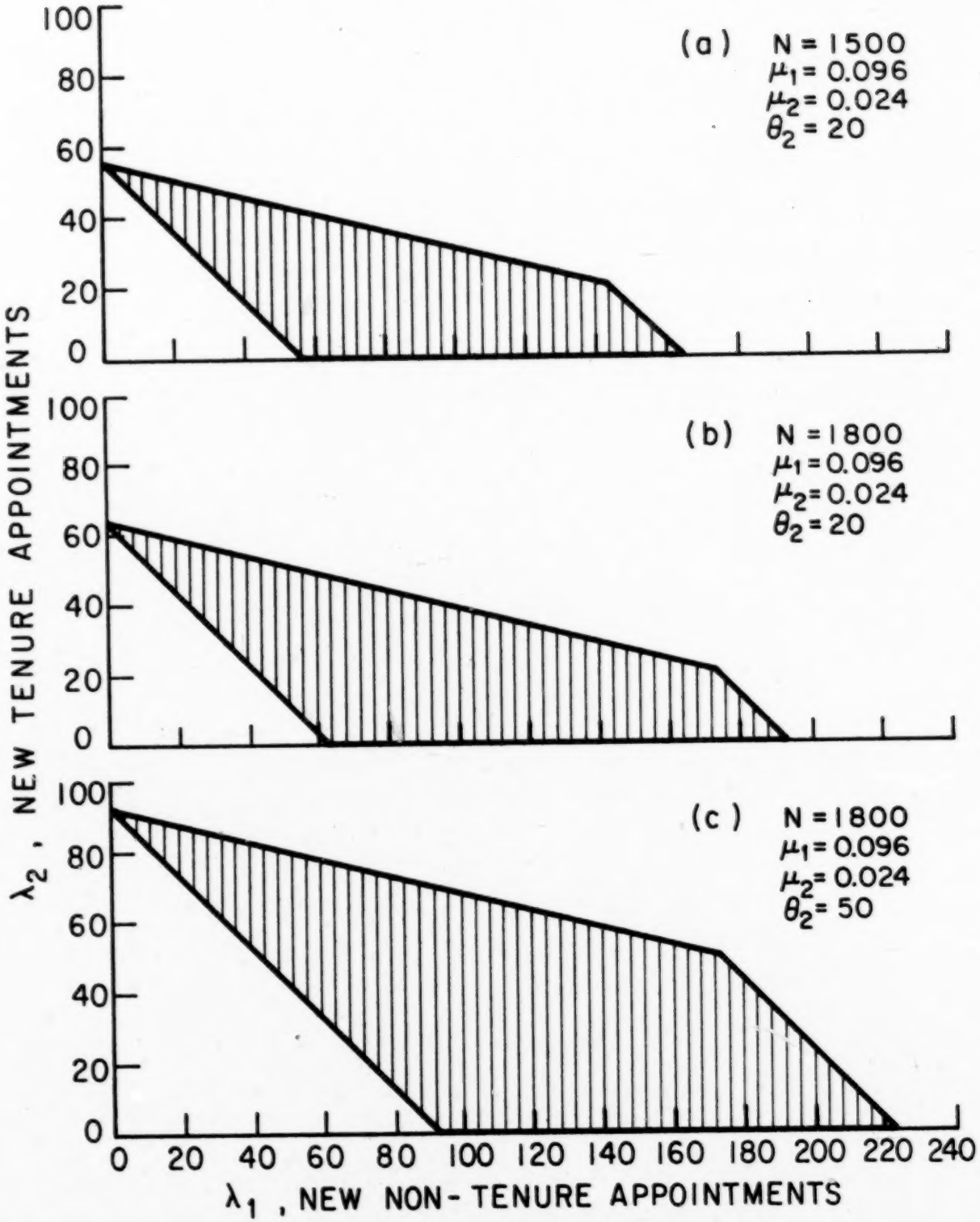
(a) N = 1500
μ_1 = 0.096
μ_2 = 0.024
θ_2 = 20
(b) N = 1800
μ_1 = 0.096
μ_2 = 0.024
θ_2 = 20
(c) N = 1800
μ_1 = 0.096
μ_2 = 0.024
θ_2 = 50
λ_2, NEW TENURE APPOINTMENTS
λ_1, NEW NON-TENURE APPOINTMENTS
0 20 40 60 80 100 120 140 160 180 200 220 240

FIG. 4 FEASIBLE APPOINTMENT RATES BASED ON BERKELEY CAMPUS DATA (1966-67)

the expected number of retirements in the years after 1990 are difficult to make even when we are willing to assume that all tenure faculty who retire do so at age 67. The unreliability of such calculations stems from the fact that resignation rates are less predictable for such distant planning horizons and, as yet unadopted appointment policies for tenure faculty will begin to have an important effect by that time. Crude estimates indicate that the number of retirements will lie somewhere between 50 and 75 per year.

In Figure (5) we show the feasible regions for nontenure and retirement rates when tenure appointment rates are given. In effect these graphs are slices of the three-dimensional feasible region made in the (θ_2, λ_1) plane rather than the (λ_1, λ_2) plane. See the discussion at the end of II.2.

It is interesting to notice that the appointment rates for 1966-67 $(\lambda_1 = 135, \lambda_2 = 40)$ lie outside the feasible regions of Figures (4a,b) and (5b,c). When retirements increase to a rate of 50 per year these appointment rates become feasible in Figure (4c) but only if θ_1 is reduced to a value of 26 tenure promotions per year selected from a total of 1136 nontenure faculty! In other words, the fractional promotion rates would have to decrease from their current values of approximately 13% to a new figure of 2%. These numbers and the resulting flows are summarized in Figure (6c). Figure (6a) corresponds to the equilibrium solution we would obtain if the linear model was applicable with fractional attrition rates based on 1966-1967 Berkeley campus data. In order to obey the conservation laws, nontenure faculty would have to drop to approximately 7% of the campus quota. In Figure (6b) we have selected smaller appointment rates which bring us well within the feasible region of Figure (4b). Although the nontenure level is approximately 44% of the quota, fractional promotion rates would still reduce to about 3% of nontenure faculty. In summary it appears that changes which bring appointment policies into feasible regions must result in fairly major changes in either nontenure levels, promotion rates from nontenure

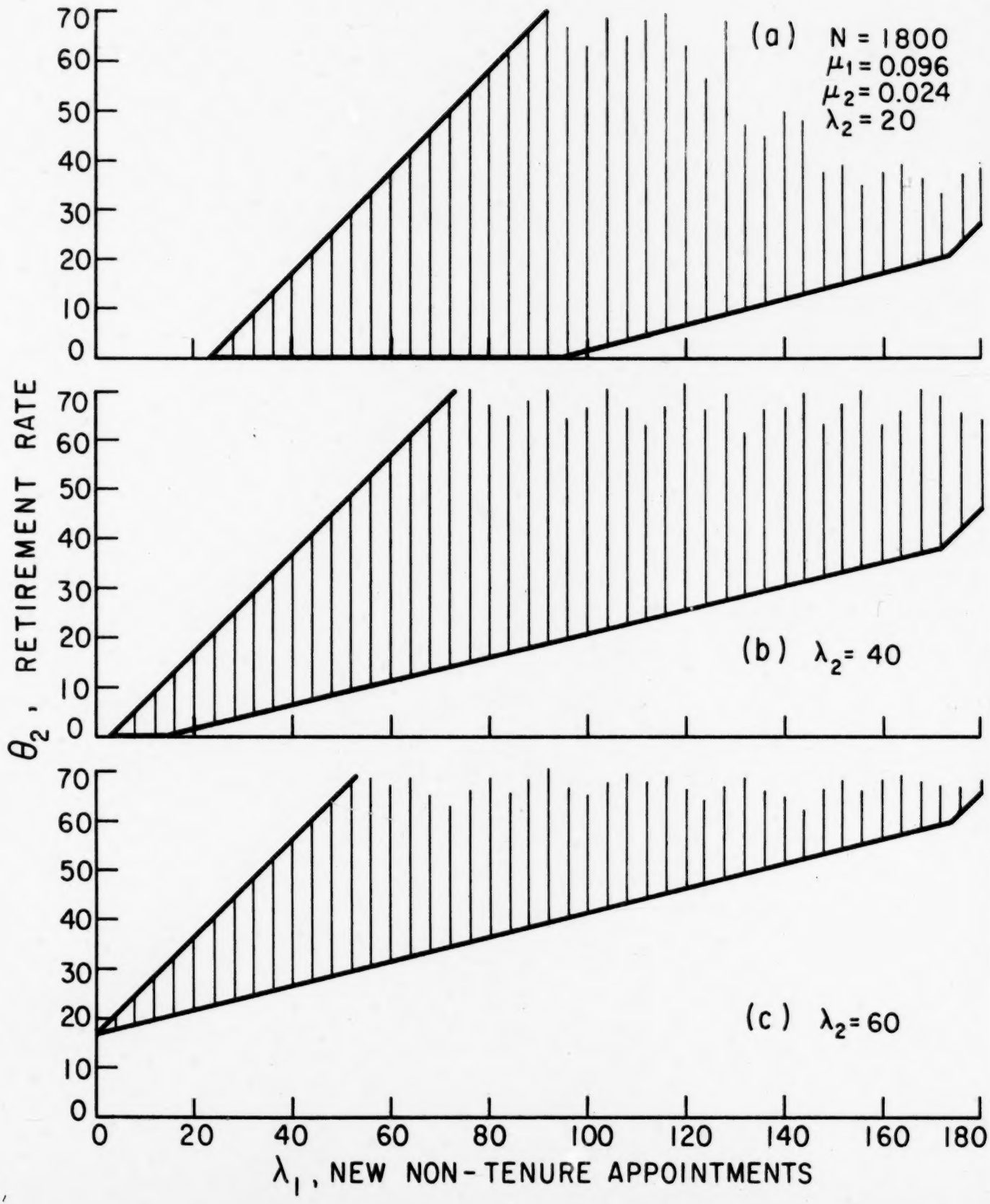

FIG. 5 FEASIBLE RETIREMENT AND NON-TENURE APPOINTMENT RATES
(Berkeley Campus Data 1966-1967)

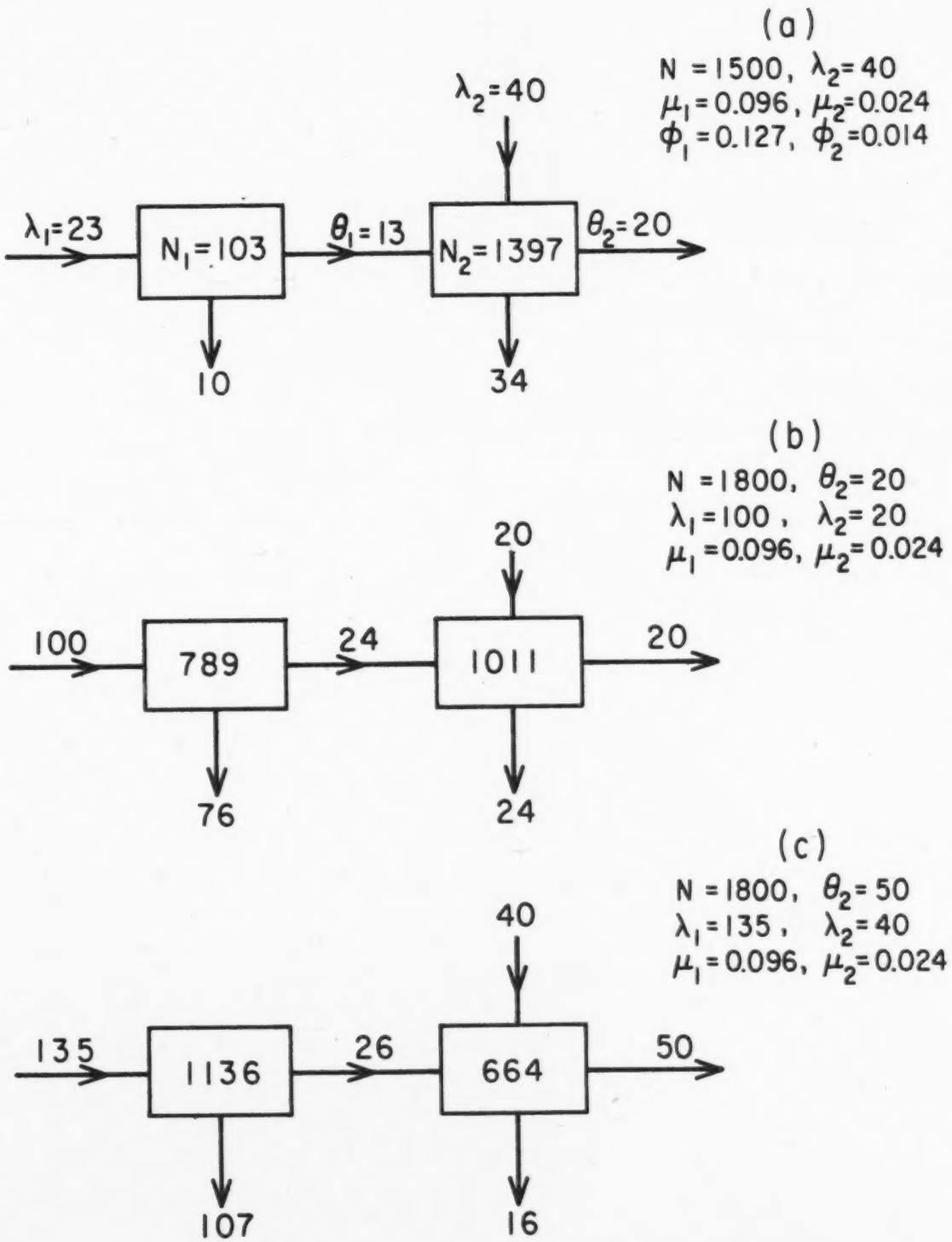

FIG. 6 FLOWS OF APPOINTMENTS, PROMOTIONS AND RETIREMENTS

(Berkeley Campus Data 1966-1967)

or early retirement.

What is the overall effect of increasing nontenure lifetimes? How do faculty levels change with increased appointment rates to tenure? If the new appointment rate to nontenure is fixed what will happen when we increase the retirement rate? Answers to questions such as these can be obtained by reference to Section II and the graphs of this section. We can briefly summarize the effect of new policies under the following headings

(a) Appointment Policies:

When resignation rates for nontenure faculty are higher than tenure faculty, $\mu_1 > \mu_2$, the number of nontenure faculty increases in direct proportion to the total rate of new appointments. For example, in those cases where we increase λ_2 one might expect to see N_2, the tenure faculty levels increase if λ_1 and θ_2 were kept constant. Actually, just the opposite effect takes place. If λ_2 is increased and λ_1 held constant then θ_1 must decrease because $\frac{d\theta_1}{d\lambda_2} = \frac{-\mu_1}{\mu_1-\mu_2} \leq 0$ from Equation (7.a). Since the flow rate of promotions decreases, the nontenure faculty levels increase and in order to maintain quota levels, the number of tenure faculty must decrease. The surprising result is that the decrease in θ_1 more than offsets the increase in λ_2 so that we always obtain reductions in tenure levels and promotions to tenure. When we use the linear models of Section II.4 a new appointment rate to one group decreases linearly as the new appointment rate to the other group increases.

(b) Increasing Service Lifetimes:

Equations (12) and (13) point out the well known fact that lifetimes in nontenure ranks may be increased in at least two ways: by decreasing promotion

rates or by decreasing resignation rates. On the other hand it is not obvious how shortening or lengthening lifetimes will affect attritions from nontenure.

Following Bressler's recommendations in 1961, Step IV was added to the Assistant Professor ranks, was essentially removed from Associate Professor and added along with Step V to the published salary scales of the Full Professor ranks. Since the average occupancy time of a step at Full Professor is probably longer than that of Assistant Professor there was probably a larger percentage increase in τ_T than in τ_N. Had we enjoyed equilibrium conditions at the time or shortly after these new salary steps were instituted the effect of nontenure fractions would have depended on whether λ_1 was held constant or allowed to vary. If the former, N_1 would have increased. Thus nontenure fractions would have increased even though there were substantial increases in tenure lifetimes. Had λ_2 been kept constant the reverse situation would occur. In retrospect the major contribution of the Bressler policies have been (a) to make our salary scales more competitive with other educational institutions and (b) to give Full Professors the opportunity to enjoy continued promotions and not have to remain at one salary step during terminal years of service.

(c) <u>New Retirement Policies</u>:

In discussing ways in which the tenure faculty ratios can be reduced one might also consider the effect of increasing retirement rates at tenure levels. In the cases where λ_1 is specified as the independent variable (Equation (13.d)) this does not appear to be a particularly interesting proposal since the only effect that this change can have is to increase the flow rate of new appointments into tenure to exactly match the increased departures from tenure. In other words the mix of tenure and nontenure remain unchanged.

On the other hand increasing ϕ_2, the retirement rate when λ_2 is specified

has quite the opposite effect. The nontenure faculty level increases because there is a larger number of total new appointments from the outside and a larger fraction entering nontenure rather than tenure. New policies for increased and early retirement will be particularly effective when new appointments are restricted by budgetary or other external factors.

(d) Nontenure Resignation Policies: In the case where λ_1 is fixed nontenure fractions decrease as μ_1 is increased. When λ_2 is fixed changes in μ_1 have no effect on N_1/N for the simple reason that the nontenure levels are held constant by simply processing more new nontenure appointments. In other words, the circulation flow into and out of nontenure increases but all other flows remain unchanged; we have a situation analogous to the case where increased retirement rates only serve to increase the flow rate of new appointments to tenure.

(e) Tenure Promotion Policies: Although we have not done so in this report it would be instructive to look at feasible regions when λ_2, θ_1 and θ_2 are the independent policy variables. In other words, policies might simultaneously take into account new retirement and new promotion rates and a redefinition of tenure independently of salary scale. Some universities do not award tenure until a faculty member has given a minimum number of years of service at the institution while other universities identify tenure with Full rather than Associate Professor.

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